Available online at www.sciencedirect.com

SCIENCE DIRECT

Renewable and Sustainable Energy Reviews
7 (2003) 469–484

RENEWABLE
& SUSTAINABLE
ENERGY REVIEWS

www.elsevier.com/locate/rser

Energy sector and wind energy potential in Turkey

R. Tuğrul Oğulata *

Faculty of Engineering and Architecture, Department of Textile Engineering, Çukurova University, Adana 01330, Turkey

Received 21 February 2003; accepted 30 June 2003

Abstract

Turkey has very limited indigenous energy resources and has to import around 65% of primary energy to meet her needs. It is a large importer of primary energy despite having ample renewable energy sources.

Turkey's vibrant economy has led to increased energy demand in recent years. This situation is expected to continue in the near future because its economy is dependent mainly on imported oil, natural gas and electricity.

This paper presents the prevailing and the expected energy situation and energy demand. Wind energy potential in Turkey is also discussed.

Keywords: Energy sector; Energy production–consumption; Energy demand; Wind energy; Wind energy potential; Turkey

Contents

* Fax: +90-322-3386-126.
E-mail address: ogulata@cu.edu.tr (R. Tuğrul Oğulata).

1364-0321/$ - see front matter
doi:10.1016/S1364-0321(03)00090-X

1. Introduction

Turkey is strategically located between the Middle and Near East. It has a dynamic economy comprising a mixture of modern industry and traditional agriculture. The share of agriculture in the economy has been decreasing as industrial and service sectors continue to expand rapidly.

Turkey's share of natural energy resources in terms of world reserves is: coal 0.6%, geothermal energy 0.8%, and hydroelectric energy 1%, though petroleum and natural gas reserves are quite limited [1].

Lignite is the dominant source of energy produced in Turkey. Nearly 75% of the indigenous lignite is consumed in thermal power plants [2].

Turkey's primary energy consumption was 80 Mtoe in 2000. It is expected to reach 167 Mtoe by 2010 and 307 Mtoe by 2020. Indigenous energy production to meet the energy demand is expected to be 33% in 2005, 30% in 2010 and 26% in 2020 [3,4].

The 27,800 MW of installed electric power capacity in 2000 has to be doubled by 2010 and increased four times by 2020 to meet Turkey's growing demand [5]. The annual rate of increase in electricity demand is around 8–10%. Turkey needs an investment of $ 4.5 billion a year until 2010 [6,7].

As its economy expands, Turkey can expect a very large growth in energy demand, especially that produced from natural gas and electricity [8]. However, since Turkey has very rich renewable energy sources, this potential should be considered as a solution to the future energy problem. Hence, wind energy holds great importance.

In this paper, the primary energy production–consumption, demand and wind energy potential in Turkey are shown in the figures and tables.

2. Energy situation in Turkey

Turkey's primary energy sources include lignite, hard coal, oil, natural gas, hydroelectricity, geothermal, wood, animal and plant wastes, solar and wind. However, these energy resources seem to be limited.

Turkey's total primary energy production covered 35% of the total energy consumption in 2000 [3,9]. In 2020, indigenous primary energy production is expected to be 26%. As seen, the amount of primary energy produced in Turkey is very low at present and in the near future too. The primary energy sources in Turkey are shown in Table 1 [4]. Turkey's primary energy production and consumption are shown in Fig. 1 [9]. As shown in the figure, primary energy consumption has been increasing rapidly. The primary energy consumption had increased from 39.1 Mtoe in 1985 to 80 Mtoe in 2000, though in the same period, the primary energy production had increased from 21.7 Mtoe to 27.6 Mtoe. As seen, Turkey is a large importer of primary energy.

Turkey's primary energy production from various sources is shown in Fig. 2 for the period 1985–2000 [4,9]. The total primary energy production in Turkey increased from 21.7 Mtoe in 1985 to 27.6 Mtoe in 2000. As shown in the figure,

Table 1
Primary energy sources in Turkey [4]

Source	Apparent	Probable	Possible	Total
Hard coal (million tons)	428	449	249	1126
Lignite (million tons)	7339	626	110	8075
Asphaltite (million tons)	45	29	8	82
Bituminous schist (million tons)	555	1086	–	1641
Hydropower (MW/year)	35,045	–	–	35,045
Oil (million tons)	48.4	–	–	48.4
Natural gas (billion tons)	8.8			8.8
Nuclear (tons)				
Uranium	9129	–	–	9129
Thorium	380,000	–	–	380,000
Geothermal (MW/year)				
Electric	200	–	4300	4500
Thermal	2250	–	28,850	31,100
Solar (Mtoe/year)[a]				
Electric	–	–	–	8.8
Heat	–	–	–	26.4

[a] Mtoe, million tons of oil equivalent.

lignite is the major primary energy source. Among the domestically produced primary energy resources, the share of oil has relatively decreased from 15.5% in 1990 to 10.6% in 2000 and the share of lignite has increased from 37.8% in 1985 to 46.5% in 2000. The share of natural gas has been negligible (2.28% in 2000) in the total primary energy production in the same period.

Turkey's primary energy consumption is shown in Fig. 3. The total consumption increased from 39.1 Mtoe in 1985 to 80 Mtoe in 2000. The share of oil is the lar-

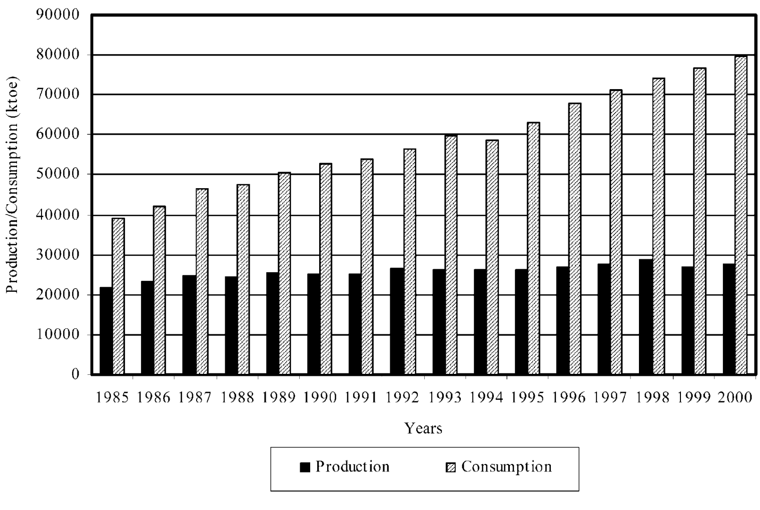


Fig. 1. Turkey's primary energy production and consumption during 1985–2000.

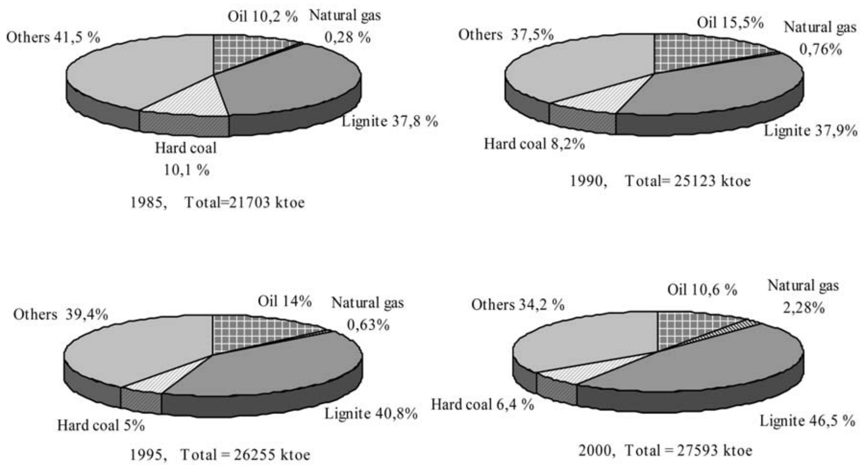


Fig. 2. Turkey's primary energy production during 1985–2000.

gest, ranging from 46.3% in 1985 to 43.8% in 2000 [4,9]. In addition, the relative share of natural gas had increased from 0.16% in 1985 to 17.6% in 2000.

Oil production and consumption in Turkey from 1985 to 2000 is shown in Fig. 4. Oil production in Turkey is nearly 3000 ktoe and oil share in the total primary energy consumption is about 44% in 2000. As seen from the data, Turkey is a small producer of oil. On the other hand, Turkey's oil consumption has increased in recent years, and this trend is expected to continue, with an annual growth of 2–3% in the coming years [8,10].

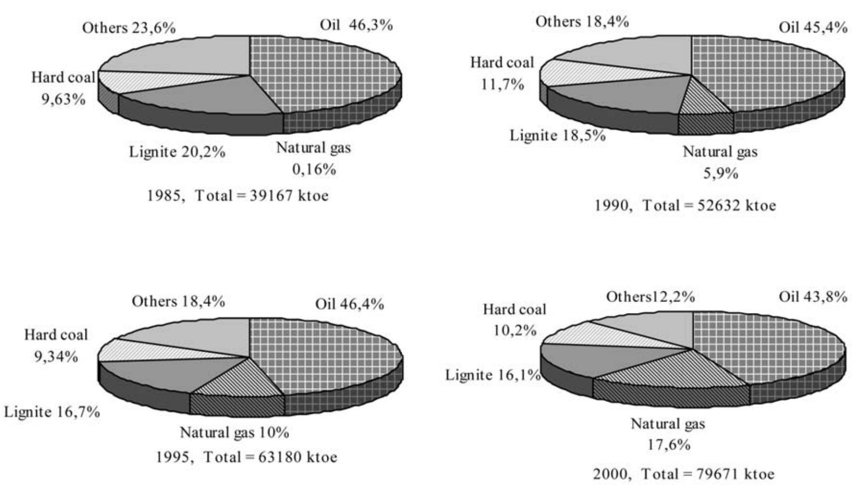


Fig. 3. Turkey's primary energy consumption during 1985–2000.

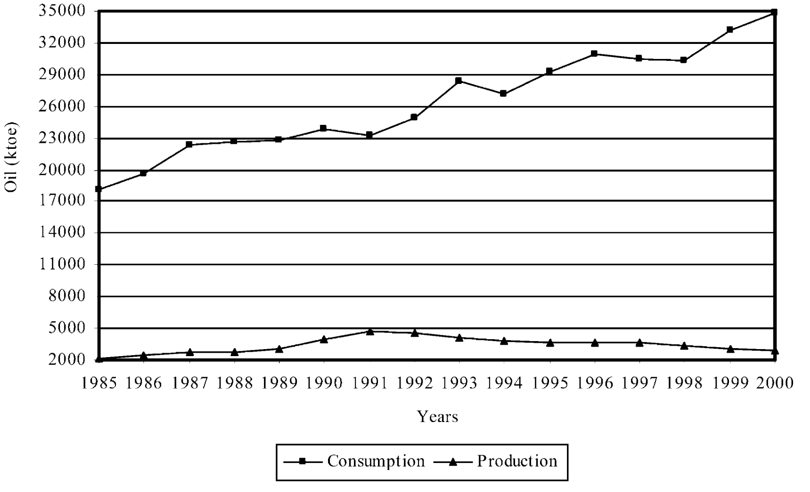


Fig. 4. Oil production and consumption in Turkey during 1985–2000.

The annual oil consumption is around 35 Mtoe and it accounted for 8.3% of oil consumption in 2000. At present, around 92% of the total oil demand is imported.

Turkey's natural gas production and consumption is shown in Fig. 5 [9]. It is seen that natural gas production is very limited. However, natural gas consumption has been increasing rapidly. Thus, nearly all natural gas is imported. The use of natural gas has increased from 62 ktoe in 1985 to 14 Mtoe in 2000. Around 70% of current Turkish gas imports come from Russia via the trans-Balkan pipeline, with the rest 30% coming mainly from Algeria and Nigeria via LNG tankers [10].

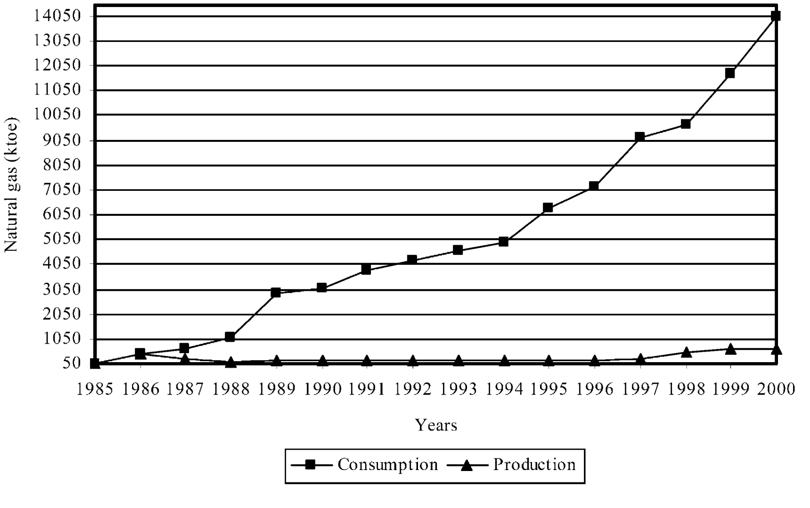


Fig. 5. Natural gas production and consumption in Turkey during 1985–2000.

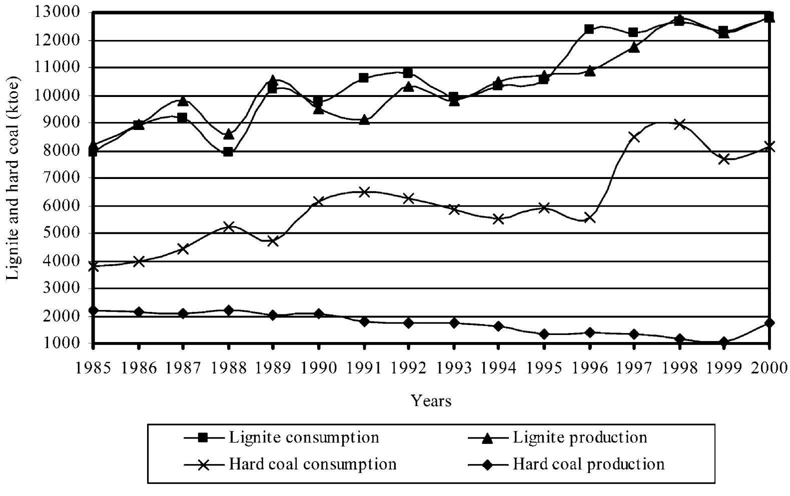


Fig. 6. Lignite and hard coal production and consumption in Turkey during 1985–2000.

Lignite and hard coal production and consumption are shown in Fig. 6 [9]. In Turkey, coal is a major fuel source. The country has 1126 million tons of hard coal and 8075 million tons of lignite [4]. Around 40% of Turkey's lignite is located in the Afsin-Elbistan basin of southeastern Anatolia, while hard coal is mined only in the Zonguldak basin of northwestern Turkey [10]. Turkey produced 12.8 Mtoe of lignite, 1.8 Mtoe of hard coal, and consumed 12.8 Mtoe of lignite, 8.15 Mtoe of hard coal in 2000. About 75% of the lignite is used as a fuel source for electric power [2].

Solar radiation and sunshine duration in various regions of Turkey are given in Table 2 [4,11]. The average solar radiation is 309.6 cal/m^2 d and the average sunshine duration is 7.2 h/d. In particular, the southeast Anatolia and the Mediterranean regions are favorable for solar energy use. Solar and geothermal energy production–consumption in Turkey are shown in Fig. 7. Generally, solar energy is used for heating and the consumption of solar energy has increased from 5 ktoe in

Table 2
Solar radiation and sunshine duration in various regions of Turkey [4,12]

Region	Solar radiation (cal/cm^2 d)	Sunshine duration (h/d)
Southeast Anatolia	344.8	8.2
Mediterranean	328.3	8.1
East Anatolia	322.4	7.3
Central Anatolia	310.3	7.2
Aegean	308.0	7.5
Marmara	275.9	6.6
Black Sea	264.5	5.4
Average	309.6	7.2

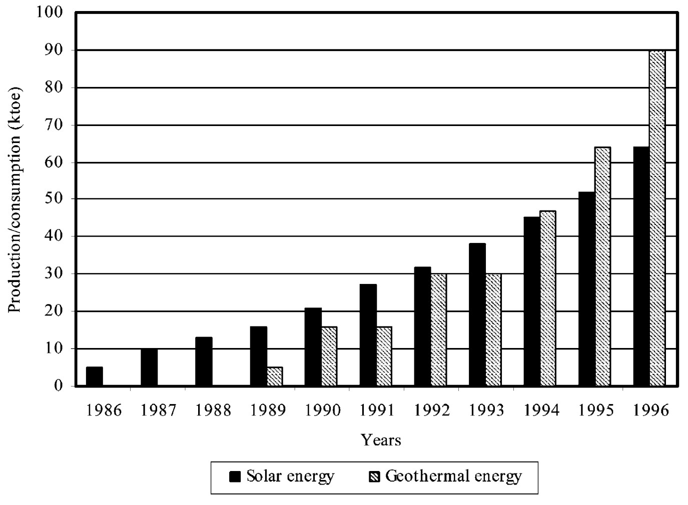


Fig. 7. Solar and geothermal energy production/consumption in Turkey during 1986–2000.

1986 to 64 ktoe in 1996 [4]. Total geothermal potential of Turkey is 35,600 MW/year (electric and thermal) and about 4500 MW/year can be used for generating electricity.

Fig. 8 shows Turkey's primary energy resource consumption forecast for 2005–2020 [4]. As seen, Turkey is dependent on import of primary energy sources. It will especially need imported oil and natural gas.

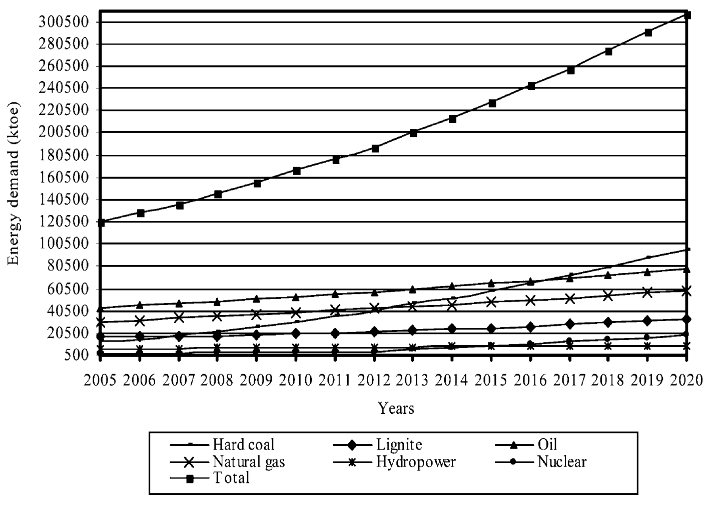


Fig. 8. Primary energy demand forecast for various sources in Turkey during 2005–2020.

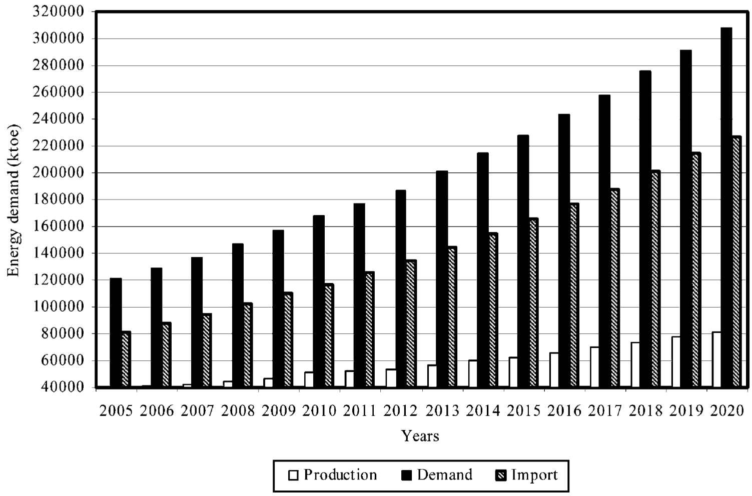


Fig. 9. Primary energy production, demand and import in Turkey during 2005–2020.

The forecast for primary energy production and demand is seen in Fig. 9 [4]. As shown in the figure, Turkey has very small primary energy sources. The import of primary energy is expected to reach 226 Mtoe by 2020, while primary energy production will increase only to 81 Mtoe in 2020. The share of imports is expected to continue to grow from 66% in 2005 to 73% in 2020.

Turkey's total electricity generation is nearly 120 TWh and electricity consumption increased to 1840 kW/h person in 1999 [1]. The installed electricity generating capacity in Turkey is shown in Fig. 10. 72% of the total electricity production was

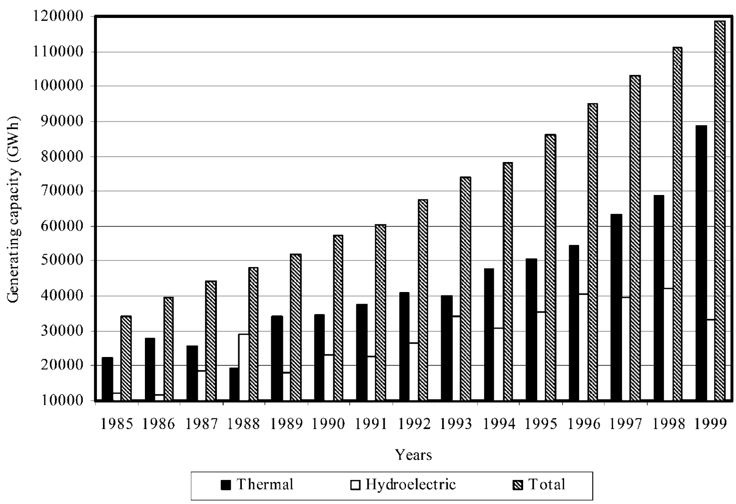


Fig. 10. Installed electricity capacity in Turkey during 1985–1999.

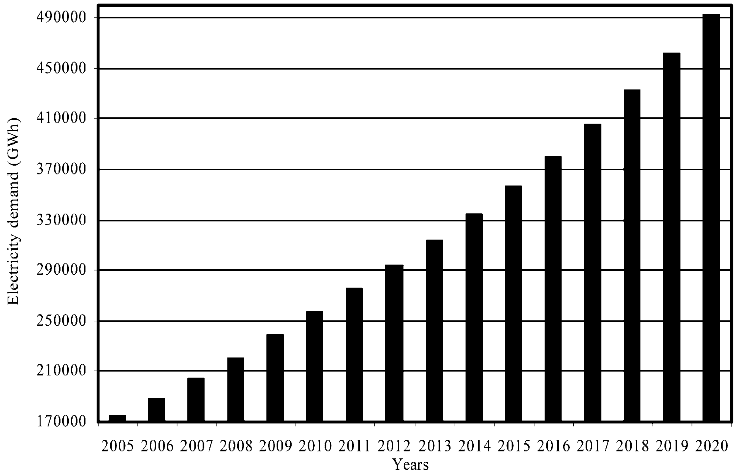


Fig. 11. Turkey's electricity consumption demand forecast during 2005–2020.

thermal energy, while hydroelectric energy accounted for the rest 28% in 1999. Coal and lignite accounted for 49.8%, fuel-oil 5.6% and natural gas 31.2% of thermal energy production [1].

Turkey has a total annual hydropotential of 433 TWh. Its share is about 14% of the total hydropower capacity in Europe. Almost half of the gross potential is technically exploitable, and 28% is economically exploitable [12]. Turkey had 108 hydroelectric power plants in operation in 1999. Installed hydroelectric power plants had a capacity of 33,104 GWh in 1999. This value is only 28% of electricity consumption in 1999. The 27,800 MW of installed electric power capacity in 2000 has to be doubled by 2010 and increased four times by 2020 to meet Turkey's growing demand [5].

Turkey's consumption of electricity is expected to continue to grow quickly at approximately 8% per year [8]. Electricity demand will increase to 175 TWh by 2005 and to 492 TWh by 2020. Fig. 11 shows Turkey's electricity consumption demand forecast for 2005–2020 [4].

3. Wind energy in Turkey

Wind energy is the fastest growing energy source in the world and wind power is one of the most widely used alternative sources of energy today. It is a clean and renewable source of electricity. At the end of the year 2001, the total installed capacity of global wind energy exceeded 24,576 MW [13]. Approximately, 6500 MW of new wind energy generating capacity were installed worldwide in 2001 [13,14]. The change of global wind power between 1998 and 2001 is shown in Table 3 [13,15,16]. The installed capacity in Europe has increased by about 40% per year in

Table 3
The change of global wind power installed capacity, MW [13]

Country	2001[a]	2000	1999	1998
Germany	8754	6095	4443	2875
USA	4258	2564	2534	1820
Spain	3337	2535	1542	834
Denmark[a]	2534	2417	1771	1383
India[a]	1500	1260	1035	992
Italy	697	427	283	178
The Netherlands	483	443	411	361
United Kingdom	474	409	347	333
China[a]	404	352	262	200
Japan[a]	316	142	68	30
Greece[a]	299	274	158	55
Sweden	290	241	215	174
Canada	198	137	125	82
Portugal[a]	153	111	61	51
Ireland	125	119	73	73
France[a]	116	63	25	21
Austria	95	77	42	30
Australia[a]	71	30	9	9
Costa Rica[a]	71	51	51	27
Egypt[a]	69	69	36	6
Morocco[a]	54	54	14	–
Poland[a]	51	5	5	5
Finland	39	39	39	18
New Zealand[a]	35	35	35	24
Belgium	31	13	9	6
Argentina[a]	27	16	15	14
Brazil[a]	24	22	19	17
Turkey[a]	19	19	9	9
Norway[a]	17	13	13	9
Luxembourg[a]	15	15	10	9
Iran[a]	11	11	11	11
Tunisia[a]	11	11	–	–
Sum	24,576	18,069	13,670	9656

[a] Estimated/preliminary.

the past six years. Today, wind energy projects across Europe produce enough electricity to meet the domestic needs of five million people [17].

The biggest share of global wind energy capacity is held by Europe at 72%. Turkey had a share of 0.11% in Europe's installed capacity in 2001. As seen in the table, the installed capacity of Turkey's wind energy has increased from 9 MW in 1998 to 19 MW in 2001. But the installed wind energy capacity is very small.

Indeed, the wind energy potential is high in Turkey though commercial wind energy is new. Turkey's first wind farm was commissioned in February 1998, having a capacity of 1.5 MW. The capacity is likely to grow rapidly, as plans have been submitted for an additional 600 MW [18]. The majority of wind energy

projects are concentrated in the Aegean and Mediterranean regions. The installed capacity of wind energy is expected to reach 600 MW by 2010 and 1000 MW by 2020 [7].

Turkey has a land surface area of about 800,000 km^2. The country is surrounded by the Black Sea in the north, the Marmara and the Aegean Sea on the west and the Mediterranean Sea in the south. Turkey has a very long coast line 8500 km [19,20]. Theoretically, Turkey has 160 TW h a year of wind potential, which is about twice as much as the current electricity consumption of Turkey [21–23]. The values of technical wind energy potential of European countries are given in Table 4 [24]. As shown in the table, Turkey has the highest share in technical wind energy potential in Europe.

Wind characteristics for some selected cities in Turkey are given in Table 5 [25,26].

Annual average wind speed and annual average wind energy potential of various regions of Turkey are shown in Table 6 [4,11,27,28]. The annual average wind speeds range from a low of 2.1 m/s in the East Anatolia region to a high of 3.3 m/s in the Marmara region. The most attractive regions for wind energy applications are the Marmara, the southeast Anatolian and the Aegean regions. These regions are highly suitable for wind power generation, since the wind speed exceeds 3 m/s in most of these areas [11].

The monthly wind speeds for high wind potential locations are given in Table 7. Measurements are taken at 10 m height above the ground [29].

As seen, the highest monthly wind speed values are determined as 11.4–13.7 m/s in Nurdağı, 8.7–11.0 m/s in Belen, 7.2–10.3 m/s in Kocadağ and 6.5–10.0 m/s in

Table 4
Technical wind energy potential of European countries [24]

Country	Total area (1000 km^2)	Technical potential	
		GW	TW/year
Austria	84	2	3
Belgium	31	2	5
Denmark	43	14	29
Finland	337	4	7
France	547	42	85
Germany	357	12	24
United Kingdom	244	57	114
Greece	132	22	44
Ireland	70	22	44
Italy	301	35	69
Luxembourg	3	0	0
Norway	324	38	76
Portugal	92	7	15
Spain	505	43	86
Turkey	781	83	166

Table 5
Wind characteristics of some cities in Turkey [25,26]

Station	Latitude N (degree)	Longitude E (degree)	Altitude (m)	Average wind speed (m/s)	
				at 5 m	at 50 m
Adana	36.59	35.20	20	1.4	2.2
Afyon	38.45	30.32	1034	2.7	3.7
Akhisar	38.55	27.51	93	2.7	4.0
Alanya	36.33	32.00	7	1.9	2.6
Anamur	36.06	32.50	5	3.1	4.3
Ankara	39.57	32.53	894	1.8	2.6
Antalya	36.52	30.44	42	2.7	3.7
Balıkesir	39.38	27.53	147	2.8	4.2
Bandırma	40.21	27.58	58	5.8	6.9
Bodrum	37.02	27.26	27	3.7	5.1
Bozcaada	39.50	26.04	40	6.2	8.4
Bursa	40.13	29.00	100	2.2	3.0
Çanakkale	40.08	26.24	2	3.9	5.4
Çorlu	41.10	27.47	183	3.8	5.3
Gökçeada	40.12	25.54	72	3.5	5.5
i nebolu	41.59	33.46	64	3.7	5.2
Isparta	37.46	30.33	1004	2.5	3.6
Malatya	38.21	38.19	898	2.7	3.7
Mardin	37.18	40.44	1080	4.3	6.0
Muğla	37.13	28.22	646	2.6	3.7
Mersin	36.48	34.36	5	2.0	2.9
Samsun	41.21	36.15	44	2.7	3.6
Sarıyer	41.10	29.03	56	2.9	4.1
Sinop	42.02	35.10	32	3.6	5.1
Van	38.30	43.23	1671	2.1	2.9

Akhisar in summer. The wind speed values are higher in summer in most of the stations.

Figs. 12 and 13 show the wind speed and the wind energy potential regional distribution for 10 m height in Turkey [30]. As shown in Fig. 12, wind speeds are

Table 6
Wind potential of various regions of Turkey [4,11,27]

Region	Annual average wind density (W/m^2)	Annual average wind speed (m/s)
Marmara	51.9	3.3
Southeast Anatolia	29.3	2.7
Aegean	23.5	2.6
Mediterranean	21.4	2.5
Black Sea	21.3	2.4
Central Anatolia	20.1	2.5
East Anatolia	13.2	2.1
Average	24.0	2.5

Table 7
Monthly wind speeds from wind data acquisition station of EIE [29]

Station	1	2	3	4	5	6	7	8	9	10	11	12
Akhisar	5.8	6.5	7.9	5.3	5.7	6.5	10.0	8.4	4.8	6.7	4.8	6.7
Bandırma	5.5	5.6	6.9	–	–	–	6.9	5.4	4.1	6.4	3.8	5.7
Belen	5.4	4.6	4.7	5.1	6.2	8.7	11.0	11.0	8.3	5.3	5.0	4.5
Datça	5.4	5.8	5.6	5.5	5.2	5.9	7.8	8.3	6.2	5.9	5.0	4.9
Didim	5.4	5.2	5.7	4.7	3.7	4.3	5.3	4.5	4.0	4.1	4.8	5.5
Gökçeada	8.4	7.9	7.8	5.4	6.2	5.3	7.4	6.5	5.8	7.3	6.8	8.3
Kocadağ	9.5	9.4	10.0	7.1	7.4	7.2	10.3	8.3	6.4	8.3	8.3	10.6
Nurdağı	3.8	4.7	4.5	6.0	–	11.4	13.7	13.7	10.7	4.8	3.3	3.2
Sinop	5.7	4.8	4.6	5.5	4.4	4.9	5.3	3.8	4.6	4.4	4.5	4.4

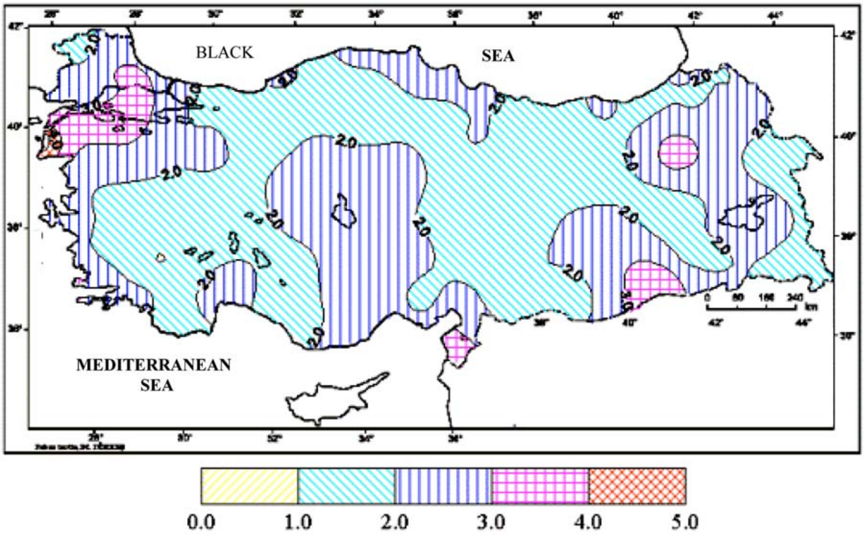


Fig. 12. Wind speed distribution in Turkey (10 m height) [30].

between 3 and 4 m/s at the northwestern corner, along the Eastern Mediterranean coast of Turkey, in the southeastern and in the northeastern of Turkey. The central Anatolian region does not provide potential wind energy locations [25]. Fig. 13 shows wind energy potential which has the highest values (50–200 W/m^2) in the same parts of Turkey.

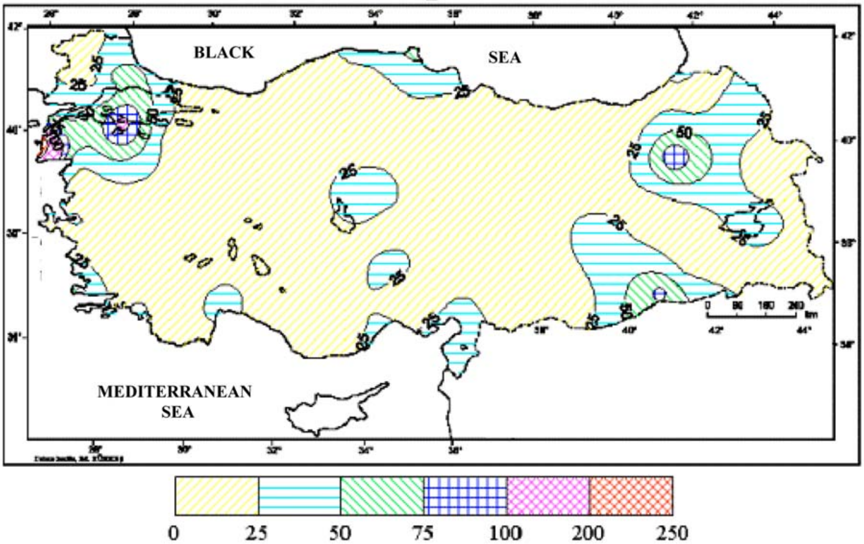


Fig. 13. Wind energy potential distribution in Turkey (10 m height) [30].

4. Conclusion

Having very limited primary energy resources, Turkey is heavily dependent on import of primary energy.

Half of Turkey's energy usage is currently oil, but natural gas usage has also increased. Natural gas consumption is expected to grow rapidly, with 64 bcm (million cubic meters) consumption projected for the year 2020 [4]. Therefore, the share of natural gas has been negligible in the total primary energy production. Also, Turkey's hydroelectric economic capacity will be fully utilized and thermal energy resources will be exhausted by the year 2010 [3].

There is no nuclear power yet in Turkey. But some new nuclear plants are expected to be built during the five-year period [31].

Turkey has a large potential of renewable energy sources. Solar and wind energy potential especially is very important. The production of geothermal and solar energy is negligible compared to that of biomass and hydropower. Wind energy almost does not have any application yet.

Wind energy has great potential. Theoretically, Turkey has 160 TWh a year of wind potential which is equivalent to twice the country's electricity production in 1996 [21]. Importance must be laid on wind energy and it needs to be developed in the near future as a source of renewable energy.

References

[1] Economic outlook, Energy IGEME web site, www.igeme.org.tr, 2002.
[2] Energy sector in Turkey, www.turkey.org, 2002.
[3] Energy sector in Turkey. Summary report of Turkish energy sector, www27.brinkster.com/hendese/energy-turkey.html, 2002.
[4] WECTNC 1997. Seventh energy congress of Turkey, Energy statistics, World energy council—Turkish national committee, Ankara 1997.
[5] Energy-Turkey, US Commercial service web site, www.sce.doc.gov, 2002.
[6] Aktas Z. Energy for Turkey and the rest of western world in the next decades, Washington 1999, Center for Strategic and International Studies, www.csis.org, 2002.
[7] Statistical data, Strategis.gc.ca web site, strategis.ic.gc.ca, 2002.
[8] An energy overview of the Republic of Turkey. Fossil energy international web site, www.fe.doe.gov, 2001.
[9] Energy in Turkey, Turkish Petroleum Corp. TPAO web site, www.tpao.gov.tr, 2002.
[10] Turkey, United States energy information administration web site, www.eia.doe.gov, 2002.
[11] Ediğer VŞ, Kentel E. Renewable energy potential as an alternative to fossil fuels in Turkey. Energy conversion and management 1999;40:743–55.
[12] Altınbilek D. Hydroelectric development plans in Turkey, State hydraulic works (DSI), Turkey web site, www.dsi.gov.tr, 2001.
[13] Global wind power statistics. New energy 3/2002, www.wwindea.org, 2002.
[14] Global wind energy market report. American wind energy association, www.awea.org, 2002.
[15] Wind energy statistics. New energy no.4, 2000, www.wind-energie.de, 2002.
[16] Wind force 10, 2001 update-crispin aubrey, www.greenpeace.de, 2002.
[17] Wind energy in Europe. EWEA web site, www.ewea.org, 2002.
[18] Turkey, overview of renewable energy policy, www.iea.org, 2002.
[19] Wind energy. http://egetek.unimedya.net.tr/pages/links/energy/wind.html, 2002.

[20] A vision for Turkish energy issues. www.egetek.org, 2002.
[21] Wind energy in Turkey. www.bsrec.bg, 2002.
[22] Uyar ST, Molly JP. Wind energy in Turkey. DEWI Magazine 1998;13.
[23] Renewable energy in Turkey. www.greenpeace.org, 2002.
[24] Uyar TS. Türkiye enerji sektöründe karar verme ve rüzgar enerjisinin entegrasyonu, www.geocities.com, 2002.
[25] Öztopal A, Şahin AD, Akgün N, Şen Z. On the regional wind energy potential of Turkey. Energy 2000;25:189–200.
[26] Kaygusuz K, Sarı A. Renewable energy potential and utilization in Turkey. Energy conversion and management 2003;44:459–78.
[27] Kaygusuz K, Kaygusuz A. Renewable energy and sustainable development in Turkey. Renewable Energy 2002;25:431–53.
[28] Kaygusuz K. Environmental impacts of energy utilisation and renewable energy policies in Turkey. Energy Policy 2002;30:689–98.
[29] The wind projects of EIE. Turkish general directorate of electrical power resources survey and development administration (EIE) web site, www.eie.gov.tr, 2002.
[30] Solar and wind energy. Turkish state meteorological services web site, www.meteor.gov.tr, 2002.
[31] Eighth five year plan 2001–2005. State planning organization (DPT), Republic of Turkey, Ankara, 2000.